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Nutrient Characteristics of the Souris River at Coulter, Manitoba, during Low Flow Years

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Abstract

A small prairie stream, the Souris River at Coulter, Manitoba, was studied in 1979/80 to determine the nitrogen and phosphorus species concentrations at a cross section of the river, and the study period data were evaluated in relation to other dry periods.

The study revealed that multiple sampling was more important for nitrogen species than for phosphorus species. It also showed that the cross-sectional variations of these species were minimal in relation to the month-to-month variations.

The 1979/80 data were found to be a fair representation of the other dry periods considered, and it was noted that the effect of the drought was most evident in the lower nitrate-N and particulate-P concentrations.

The major nitrogen species identified were total dissolved organic-N, ammonia-N, and particulate-N; the major phosphorus species were ortho-P, particulate-P, and total dissolved organic-P.

Periodic water releases from the J. Clark Salyer Reservoir proved to be an important factor affecting the nutrient species concentration. The data also revealed that the Souris River was an inorganic-N–limited stream rather than an ortho-P–limited one.

Résumé

La rivière Souris, un petit cours d'eau de prairie près de Coulter au Manitoba, a fait l'objet d'une étude en 1979-1980 en vue de déterminer les concentrations des diverses formes d'azote et de phosphore dans une coupe transversale. On a établi une comparaison entre les données de cette étude et celles obtenues au cours d'autres périodes de sécheresse.

Les résultats ont montré que l'échantillonnage multiple était plus important pour les formes d'azote que pour celles de phosphore, et que la variation des concentrations dans la coupe transversale était minime par rapport à la variation mensuelle.

On a trouvé que les données de 1979-1980 correspondaient assez bien à celles qui avaient été recueillies pendant les autres périodes de sécheresse. De plus, on a constaté que la sécheresse entraînait la réduction de la concentration la plus basse de N sous forme de nitrate et de P particulaire.

On a identifié la présence d'azote surtout sous forme de N organique total dissous, de N ammoniacal et de N particulaire. De même le phosphore était présent surtout sous la forme d'orthophosphate, de P particulaire et de P organique total dissous.

La libération périodique de l'eau du réservoir J. Clark Salyer a eu de toute évidence un effet important sur la concentration des éléments nutritifs. Les données ont aussi révélé que la rivière Souris était un cours d'eau limité en azote inorganique plutôt qu'en orthophosphates.

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INTRODUCTION

Background and Objectives

The Garrison Diversion Unit Project (GDUP) is a multifaceted water development scheme, which if fully implemented would transfer water from the Missouri River to the drainage basin of the Souris and Red rivers (International Garrison Diversion Study Board, 1976a). The implementation of this scheme, as originally envisaged, could adversely affect the water quality in Canada, as it would include the input of additional nutrient-rich return flow into the already nutrient-rich Souris River (United States Environmental Protection Agency, 1971) and eventually into the south basin of Lake Winnipeg, which is reported to be already nearing a eutrophic state (Brunskill, 1974).

The Souris River is a source of raw water for potable water supply, irrigation, and stock watering, as well as for recreational uses such as fishing, boating, and swimming. The water quality is marginal, and even a small increase in contaminants could render the water unfit for some of the above uses (United States Environmental Protection Agency, 1971).

Although monthly total-N, nitrate- and nitrite-N, and total-P data have been available since 1973, the International Garrison Diversion Study Board (IGDSB) (1976b) concluded that the nutrient data base (nitrogen and phosphorus) for the Souris River was weak and that a better understanding of the nutrient species was essential for determining "the nature and extent of the complex nitrogen transformations in the Souris and Red Rivers." In its report, the IGDSB also pointed out the lack of water quality data during dry periods and thus the need for obtaining such data. Similar concern was expressed by the Manitoba Clean Environment Commission (1980) when it observed that sufficient phosphorus data were not available for establishing phosphorus level objectives in the Souris River. Thus, there has been a well-recognized need for further characterizing the nutrient quality of the Souris River, particularly during a dry period.

A study was undertaken during a dry period, August 1979 to August 1980, which included a multiple sampling scheme and nutrient species determination. Results obtained from this special study and data from Water Quality Branch routine monitoring during other dry periods (1973, 1977, 1978, 1980, and 1981) are the subject of this paper. This paper will

1. assess the representativeness of a single sample from the river cross section;
2. evaluate the 1979/80 data in relation to other dry periods; and
3. determine the concentration and ratio of the nitrogen and phosphorus species in the Souris River.

Study Area

The Souris River is an international stream that originates in Saskatchewan, flows through North Dakota, and re-enters Canada at the southwest corner of Manitoba (Fig. 1). The total river basin (approximately 60 000 km^2) lies within the nutrient-rich agricultural areas of Saskatchewan, North Dakota, and Manitoba. Non-point surface runoff is a major source of nitrogen and phosphorus to the river. Despite the seasonal cleansing characteristics of wetland marshes, wildlife refuges situated along the river, such as the J. Clark Salyer Reservoir, contribute considerably to the nutrient load in the Souris River (Manitoba Clean Environment Commission, 1980). Municipal effluent from communities such as Minot, Velva, and Towner also are known to contribute to the content of this river (United States Environmental Protection Agency, 1971).

Flows in the Souris River are extremely variable, having a short period of spring runoff and a very low flow through the remainder of the year. Under an interim flow apportionment agreement of 1959, North Dakota is required to maintain a flow of 0.57 m^3/s from June to October inclusive at the point where the river enters Manitoba, except during periods of severe drought, when it is required to provide adequate flows to accommodate

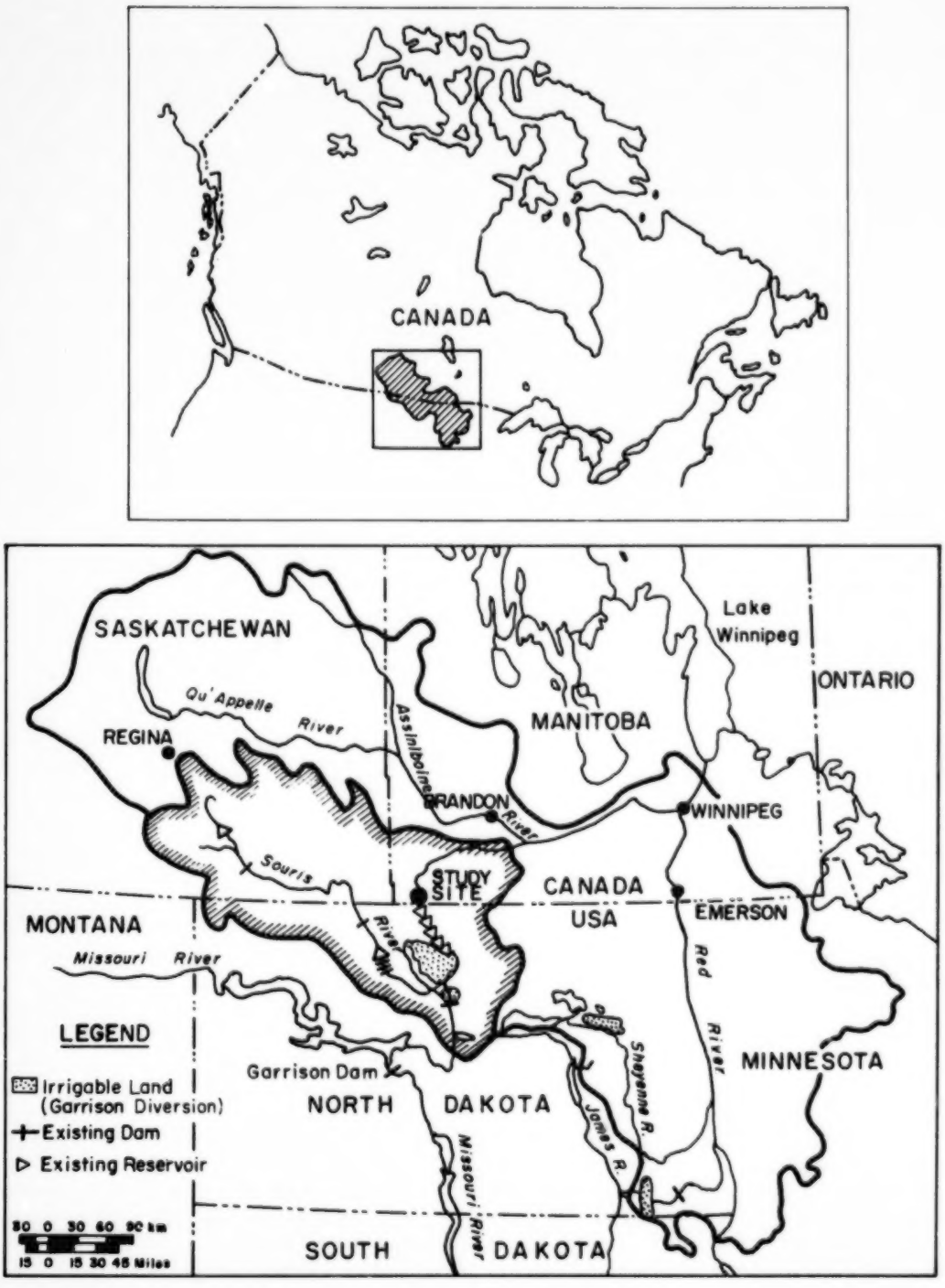

Figure 1. Souris River basin and study site.

human and livestock consumption and household uses. This apportionment agreement, however, does not cover the winter periods, when the flow is very low and anaerobic conditions exist.

METHODOLOGY

Field Procedures

Routine Single Samples

Routine single samples for total-N, nitrate- and nitrite-N, and total-P are collected monthly at Highway 251 employing the standard Water Quality Branch sampling procedures as described in the manuals (Environment Canada, 1973; Water Quality Branch, 1979). Additional samples have been collected either by the Water Resources Branch staff or under the Souris River Basin Study Project, also employing the Branch sampling procedures. Samples are collected by lowering and retrieving a polyethylene bottle in midstream. Values obtained from this procedure reflect a one-time concentration at a particular site. No internal preservatives are added, but the samples are shipped in ice-packed containers. Generally, these samples are analysed three to five days after collection.

Special Study Multiple Samples

Multiple samples were collected during each of the 14 trips conducted between August 1979 and August 1980. A cross section of the Souris River at Highway 251 was graphically divided into grids of 1 m^2 or smaller during the low flow seasons (Fig. 2). A closed acrylic sampler was lowered to each grid and a sliding messenger was used to open the sampler. Samples were retrieved one after another from 12 randomly generated grids. The samples were transferred to polyethylene bottles and transported to Winnipeg in ice-packed containers. No internal preservatives were added. Analysis for dissolved constituents and filtration for the particulates were carried out within 24 hours after the collection.

Laboratory Procedures

Routine Single Samples

The routine samples were analysed in the Water Quality Branch laboratory in accordance with procedures described in the *Analytical Methods Manual* (Environment Canada, 1974 and 1979). The total-N values were obtained by adding either the Kjeldahl-N and nitrate- and nitrite-N values or the total dissolved-N and particulate-N values. Both of these methods are considered satisfactory in determining the total-N concentration. The less-than-detection values (only for nitrate- and nitrite-N) were interpreted as equal to the numeric value of detection. Total-P was analysed directly, and the concentrations were always above detection limits.

Special Study Multiple Samples

The multiple samples were analysed by the Department of Fisheries and Oceans at the Freshwater Institute in Winnipeg, Manitoba. Nutrient species analyses were carried out for ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), total dissolved nitrogen (TDN), particulate nitrogen (PN), ortho-phosphorus (oP), total dissolved phosphorus (TDP), and particulate phosphorus (PP). Concentrations of total dissolved organic nitrogen (TDON), total nitrogen (TN), total dissolved organic phosphorus (TDOP), and total phosphorus (TP) were calculated. The analytical procedures were those described by Stainton *et al*. (1974).

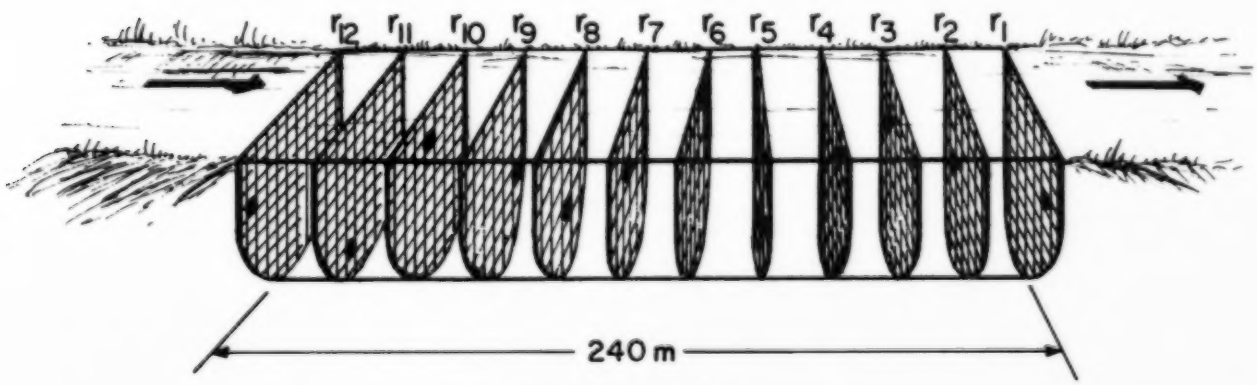

Figure 2. Sampling locations.

Comparability of the Routine Single Sample and the Special Study Multiple Sample Data

As noted earlier, there were differences in sampling techniques, in time lapses between sample collection and analysis, and in analytical procedures. Despite the differences in analytical procedures, the data provided by both laboratories are considered accurate and thus comparable, since both of these laboratories are involved in extensive internal and identical external quality control programs. With regard to the sampling techniques and time lapse, the following assumptions were made. The mean of the multiple samples and the integrated one-routine sample are comparable, and the deterioration of the routine sample (total-N, nitrate- and nitrite-N, and total-P), because of the greater delay in analysing it, is minimal.

Discharge Data

All discharge data used in this paper are those provided by the Water Resources Branch (Environment Canada, 1981 and 1983). Discharge data were obtained from two sites located approximately 20 km apart. The upstream site is located at Westhope, North Dakota, and the other site is at Coulter, Manitoba. Data collection at the Coulter site, which is the focus of this study, was started in 1977. A comparison of the 1977–80 data (simple regression) yielded a correlation (R^2) of 0.996, suggesting good agreement between these sites. The earlier Coulter discharge data used in this paper are corrected for the difference.

RESULTS

Multiple Samples from the River Cross Section

The estimated mean velocity of the river on the days in which the samples were collected was 8 m/min. The average sampling time of each set of 12 samples was 30 min. This time period, therefore, represents a volume of water occupying a 240-m reach of the river (Fig. 2) from which the sequential samples were collected. These sequential samples henceforth are referred to as replicate samples of the 240-m reach on the cross section of the Souris River at Highway 251.

In order to estimate the variation within the 12 replicate samples, a precision value was calculated. The sample precision and the analytical precision are given in Table 1. When the replicate sample precision (reported as the coef-

Table 1. Replicate Sample Precision Compared with Analytical Precision

	Nitrogen species					Phosphorus species		
	NH_3-N	NO_2-N	NO_3-N	TDN-N	PN-N	oP-P	TDP-P	PP-P
Analytical precision	2	20	6	2	8	N.A.	N.A.	8
Sampling date								
79-08-02	55.3	88.9	172.2	12.8	36.2	1.4	2.0	47.4
79-08-21	37.6	37.0	75.0	12.6	79.0	2.0	2.0	31.5
79-09-27	28.6	45.5	32.1	6.7	47.3	3.8	3.2	54.7
79-10-29	63.3	39.0	130.2	5.3	14.3	18.7	6.7	11.4
79-11-28	16.4	<0.1	16.2	12.1	27.0	4.4	2.1	20.7
79-12-19	10.5	12.3	3.2	5.3	33.6	4.5	6.6	20.4
80-01-29	3.7	12.3	10.1	40.8	31.9	2.7	2.8	3.2
80-02-26	2.3	<0.1	180.9	8.3	36.9	4.7	5.4	5.5
80-03-25	2.3	<0.1	121.7	14.3	53.7	2.0	1.5	7.7
80-04-29	65.3	31.6	131.8	10.6	38.9	8.8	5.3	41.3
80-05-22	35.8	<0.1	126.3	20.0	36.7	22.0	16.4	29.6
80-06-17	87.0	<0.1	180.0	18.9	46.3	15.6	7.2	40.7
80-07-30	5.5	13.9	154.3	5.0	20.9	2.7	1.9	26.6
80-08-13	4.7	8.6	30.3	10.2	50.7	1.9	1.9	13.9

Note: Replicate sample precision is reported as twice the coefficient of variation in percent $\left(\frac{s}{\bar{X}} \times 200\right)$; n = 12.

Analytical precision was determined from six sub-samples of a homogenized Canadian Shield water sample.

N.A. = not available.

ficient of variation) is a small value, it suggests good analytical and sampling (collection and preservation) techniques, no changes or identical rate of changes in all sample bottles, and cross-sectional homogeneity. When a large precision value is obtained, it suggests analytical and sampling variation, different rate of changes in the sample bottles, cross-sectional heterogeneity, or a combination of all of these. Overall, the analytical variation was small in comparison with the replicate sample variations. An exception was the nitrite-N, which had several smaller replicate variations. The reason for these smaller values was that most of these concentrations were reported as less-than-detection limits, thus resulting in identical values and smaller variation. Nitrate-N had the largest replicate variation. The extent to which the expected high variability near the analytical detection affected the nitrate-N variation is unknown.

Replicate variation in terms of Student's t distribution at 95% confidence is also given in Figure 3. Here, the replicate sample variations are seen in relation to the monthly mean concentrations. Although for some species, such as ammonia-N, nitrite-N, and ortho-P, the replicate variation was small during the winter, it differed substantially during the study period, and generally it was greater for the nitrogen species than for the phosphorus species.

Historical Data from Other Dry Periods

The annual mean discharge in the Souris River fluctuated substantially (Appendix A). The sixties were a relatively dry period; the seventies had relatively high precipitation, with the exception of 1973, 1977, and 1978; and 1980 and 1981 were dry years. For the purpose of this paper, a dry year is defined as a year with an manual mean discharge of less than 4.0 m^3/s.

Summary statistics of nutrient data during various flow periods of the dry years and of the study period are given in Table 2. In order to allow comparison of seasonal statistics and to minimize flow-related variability in nutrients, the periods in Table 2 were determined from examination of the annual hydrograph. The "spring high flow" period was empirically defined as the period between the slope of the hydrograph on either side of the spring peak. This period was followed by the "low flow, open water" period, which continued until ice formation. Freeze-up marked the beginning of the third period, "low flow under ice cover," which continued until the rise in the hydrograph in spring.

Data in Table 2 show that maximum total-N and total-P concentrations usually occurred during the low flow period under ice cover, and maximum nitrate- and nitrite-N during the low flow, open water period. Data in Table 2 also reveal that with the exception of total-N and nitrate- and nitrite-N during the spring high flow, the mean concentrations of the dry years were within the variation range observed during the study period. Total-N was slightly above the study period maximum, but nitrate- and nitrite-N was substantially above the 0.01 mg/L maximum observed during the study period. However, the 0.08 mg/L mean of the dry years was inflated by one abnormally high value obtained in 1978 when the spring runoff was the highest of the dry years considered in this paper. Deletion

Table 2. Summary Statistics of Nutrient Data during Various Flow Periods

	Study period					Dry periods*				
Parameters and flow periods	Mean	Std. dev.	Min.	Max.	N	Mean	Std. dev.	Min.	Max.	N
TN-N (mg/L)										
Spring high flow	1.19	0.17	0.94	1.34	4	1.40	0.35	0.83	1.99	7
Low flow, open water	2.48	1.21	1.45	4.02	5	2.57	1.54	0.74	8.11	25
Low flow under ice cover	3.04	0.87	1.84	4.02	5	2.44	1.01	1.27	5.83	21
NO_3-N and NO_2-N (mg/L)										
Spring high flow	0.01	<0.01	<0.01	0.01	4	0.08	0.18	<0.01	0.50	7
Low flow, open water	0.15	0.28	<0.01	0.64	5	0.22	0.41	<0.01	1.80	26
Low flow under ice cover	0.08	0.09	<0.01	0.21	5	0.09	0.10	<0.01	0.41	21
TP-P (mg/L)										
Spring high flow	0.25	0.09	0.17	0.38	4	0.23	0.12	0.10	0.47	7
Low flow, open water	0.31	0.18	0.14	0.57	5	0.34	0.24	0.05	1.15	31
Low flow under ice cover	0.87	0.80	0.16	2.02	5	0.43	0.44	0.09	1.90	20

*1973, 1977, 1978, 1980, and 1981.

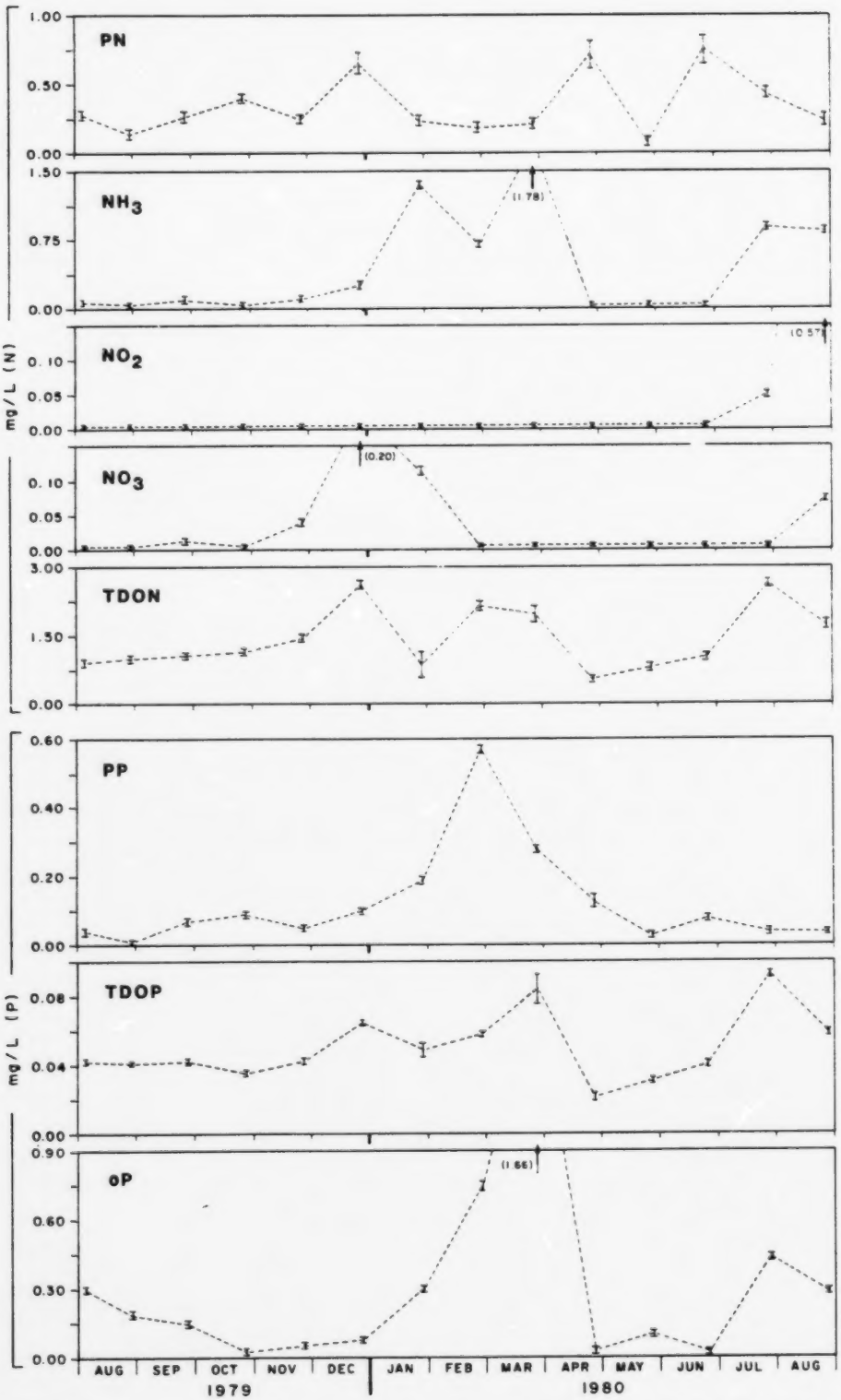

Figure 3. Replicate sample variation in relation to the study period variation. Confidence limit about the mean is calculated from $\left(\overline{X} \pm \frac{(s)\ (t)}{\sqrt{n-1}}\right)$ where $\overline{X}$ = sample mean, s = standard deviation, t = Student's value at 0.05, and n = 12.

of this one value (0.5 mg/L) yielded a mean concentration of 0.01 mg/L, which was identical to the study period mean. Therefore, even the nitrate- and nitrite-N was probably within the study period variation range.

A yearly breakdown of the flow periods is given in Figure 4. The highest discharge during the study period and other dry years occurred in 1978 during the spring high flow period; the highest total-N concentration occurred

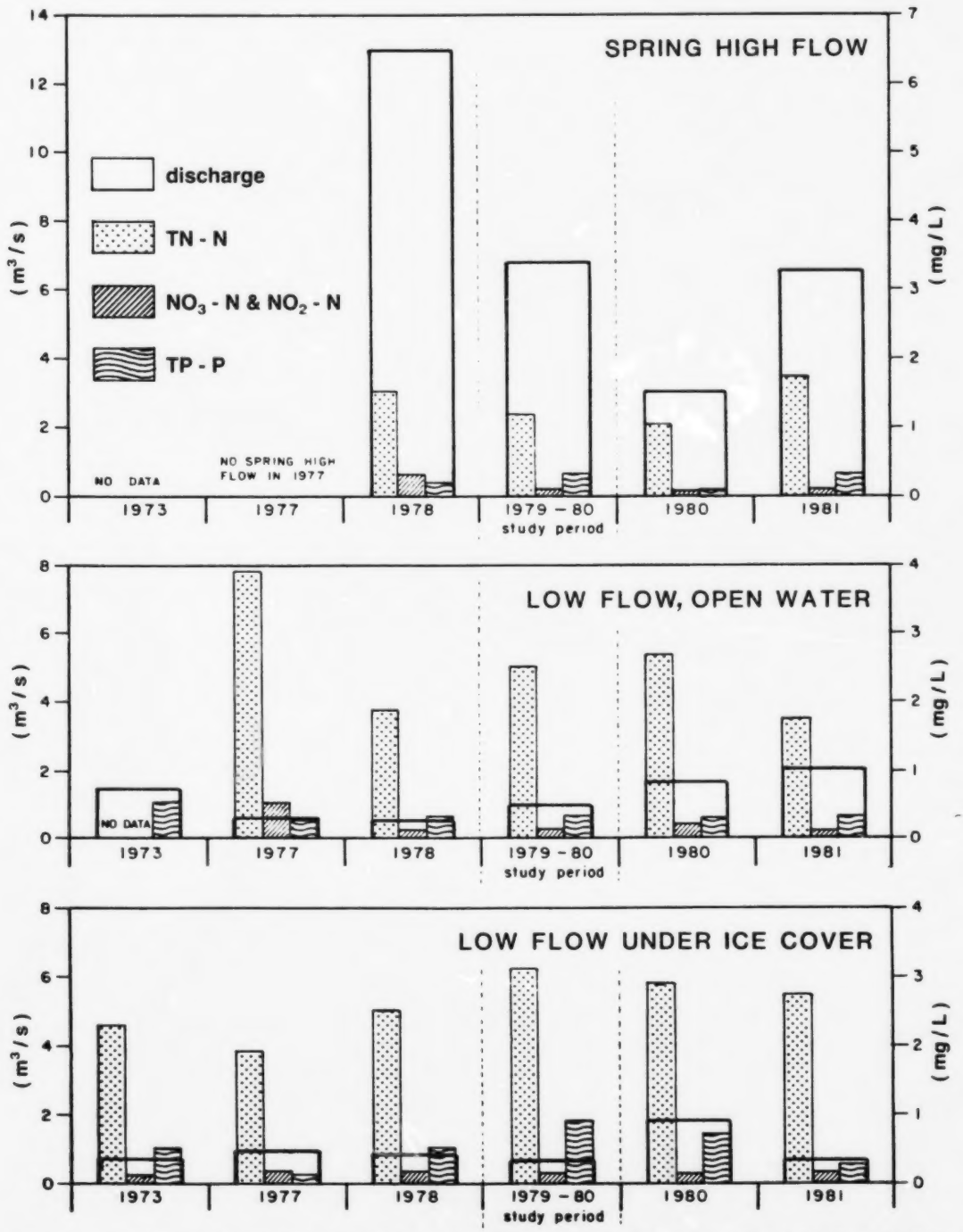

Figure 4. Mean discharge of sampling days and mean nutrient concentration of the dry years and special study period during various flow periods. Mean concentration calculated from two to seven samples.

Table 3. Mean Concentrations of Nitrogen and Phosphorus Species during the Study Period (mg/L)

	Nitrogen species							Phosphorus species				
	NH_3-N	NO_2-N	NO_3-N	TDON-N	TDN-N	PN-N	TN-N	oP-P	TDOP-P	TDP-P	PP-P	TP-P
Sampling date												
79-08-02	0.06 (5)	<0.01 (<1)	<0.01 (<1)	0.99 (74)	1.06 (79)	0.28 (21)	1.34	0.30 (79)	0.04 (11)	0.34 (90)	0.04 (11)	0.38
79-08-21	0.04 (3)	<0.01 (<1)	<0.01 (<1)	1.04 (85)	1.09 (89)	0.13 (11)	1.22	0.20 (77)	0.04 (15)	0.24 (92)	0.02 (8)	0.26
79-09-27	0.10 (7)	<0.01 (<1)	0.02 (1)	1.07 (74)	1.19 (82)	0.26 (18)	1.45	0.16 (57)	0.05 (18)	0.21 (75)	0.07 (25)	0.28
79-10-29	0.03 (2)	<0.01 (<1)	0.01 (<1)	1.13 (72)	1.17 (75)	0.40 (26)	1.57	0.03 (20)	0.03 (20)	0.06 (40)	0.09 (60)	0.15
79-11-28	0.09 (5)	<0.01 (<1)	0.04 (2)	1.44 (78)	1.58 (86)	0.26 (14)	1.84	0.06 (38)	0.05 (31)	0.11 (69)	0.05 (31)	0.16
79-12-19	0.24 (7)	0.01 (<1)	0.20 (5)	2.61 (70)	3.06 (83)	0.65 (18)	3.71	0.08 (33)	0.06 (25)	0.14 (58)	0.10 (42)	0.24
80-01-29	1.34 (52)	0.01 (<1)	0.12 (5)	0.87 (34)	2.34 (90)	0.26 (10)	2.60	0.30 (56)	0.05 (9)	0.35 (65)	0.19 (35)	0.54
80-02-26	0.72 (24)	<0.01 (<1)	<0.01 (<1)	2.14 (70)	2.86 (94)	0.20 (7)	3.06	0.74 (54)	0.06 (4)	0.80 (58)	0.57 (42)	1.37
80-03-25	1.78 (44)	<0.01 (<1)	0.01 (<1)	2.02 (50)	3.80 (95)	0.22 (6)	4.02	1.66 (82)	0.08 (4)	1.74 (86)	0.28 (14)	2.02
80-04-29	0.02 (2)	<0.01 (<1)	<0.01 (<1)	0.51 (40)	0.54 (43)	0.73 (58)	1.27	0.03 (17)	0.02 (11)	0.05 (28)	0.13 (72)	0.18
80-05-22	0.06 (6)	<0.01 (<1)	<0.01 (<1)	0.79 (83)	0.85 (90)	0.10 (11)	0.95	0.11 (69)	0.03 (19)	0.14 (88)	0.02 (13)	0.16
80-06-17	0.04 (2)	<0.01 (<1)	<0.01 (<1)	1.01 (56)	1.05 (58)	0.75 (42)	1.80	0.02 (14)	0.04 (29)	0.06 (43)	0.08 (57)	0.14
80-07-30	0.92 (23)	0.05 (1)	0.01 (<1)	2.61 (65)	3.59 (89)	0.43 (11)	4.02	0.43 (75)	0.10 (18)	0.53 (93)	0.04 (7)	0.57
80-08-13	0.86 (24)	0.57 (16)	0.08 (2)	1.77 (50)	3.28 (92)	0.27 (8)	3.55	0.29 (74)	0.06 (15)	0.35 (90)	0.04 (10)	0.39
Study mean	0.45 (20)	0.05 (2)	0.04 (2)	1.43 (62)	1.96 (85)	0.35 (15)	2.31	0.32 (65)	0.05 (10)	0.37 (76)	0.12 (25)	0.49

Note: Percentage of total concentration is shown in parentheses.

in 1977 during the low flow, open water period; and the highest total-P concentration occurred in the study period during low flow under ice cover. These high values are discussed in the section Nutrient Concentration of the Study Period and Other Dry Periods.

Nitrogen and Phosphorus Species

The mean concentration and ratio (percentage of total) of the nitrogen and phosphorus species are given in Table 3. Total dissolved organic-N was the predominant nitrogen species of the study period, accounting for 62% of the total-N. It varied from 0.51 mg/L in April to 2.61 mg/L in December and July. Ammonia-N was the second most abundant nitrogen species in the Souris River, varying from 0.02 mg/L in April to 1.78 mg/L in March. Nitrate-N concentrations were very low, ranging from <0.01 to 0.20 mg/L, with a study mean of 0.04 mg/L. Nitrite-N ranged from <0.01 to 0.57 mg/L, and particulate-N constituted 15% of the total-N, with highs in April and June.

Ortho-P was the predominant phosphorus species in the Souris River, constituting 65% of the total-P. Total dissolved organic-P remained virtually constant between 0.02 and 0.10 mg/L. Polyphosphorus was determined in three sets of samples. The mean concentration was less than 0.004 mg/L, indicating very low concentration in the Souris River. Particulate-P varied from a low of 0.02 mg/L in May to 0.57 mg/L in February, with a study period mean of 0.12 mg/L.

The site measurements at the time of the replicate sampling are given in Table 4. All parameters varied substantially during the study period. The winter period, with 0°C water temperature, had relatively low pH, very high conductivity, and very low dissolved oxygen content.

Table 4. Site Measurements at Time of Replicate Sample Collection

Sampling date	Water temp. (°C)	pH	Conductivity (μmhos)	Dissolved oxygen (mg/L)
79-08-02	21.5	8.7	800	8.3
79-08-21	21.0	8.7	800	8.1
79-09-27	13.5	8.2	900	8.6
79-10-29	5.0	8.1	990	12.3
79-11-28	0.0	7.9	1380	14.3
79-12-19	0.0	7.6	2600	7.2
80-01-29	0.0	7.4	3000	7.2
80-02-26	0.0	7.3	2900	0.5
80-03-25	0.0	7.2	3900	0.0
80-04-29	15.0	7.7	550	9.6
80-05-22	18.5	8.1	800	8.0
80-06-17	19.0	8.6	900	9.6
80-07-30	18.5	8.1	1100	2.3
80-08-13	18.0	7.6	1000	3.3

DISCUSSION

Single-Sample and Cross-sectional Homogeneity

As noted in the section Multiple Samples from the River Cross Section, the replicate sample variation is a function of analytical and sampling variations, changes occurring in the sample bottles, and heterogeneity of the river cross section. It was also observed that the replicate sample variation was not uniform throughout the study period and generally that the analytical variation was small in comparison to the replicate variation.

When the analytical variation is removed from the replicate variation, it reflects the sampling variation, changes occurring in the sample bottles, and cross-sectional heterogeneity. During the special study, all samples were collected and preserved employing identical techniques; therefore the sampling variation is considered small. However, as reported by various authors (Klingaman and Nelson, 1976; Whitfield and McKinley, 1979), nitrogen and phosphorus species can undergo transformation in the sample bottles prior to analysis. If the rate of change was different in any of the 12 sample bottles collected during each trip, part or all of the observed replicate variation could be attributed to these changes. This, however, was probably not a major factor in this study because the samples were treated identically and were either analysed or filtered for particulates within 24 hours after collection.

Overall, the replicate variations of total dissolved-N and particulate-N were greater than that of total dissolved-P and particulate-P, respectively. Ortho-P and total dissolved-P had the smallest replicate variation. A previous study conducted in the Red River (Chacko *et al.*, 1981) also revealed a similar pattern. Therefore, these observations show that replicate sampling is more important for nitrogen species than for phosphorus species. However, further investigation is required in order to establish to what extent the observed sample variation is caused by the river cross-sectional heterogeneity rather than by the different rates of change occurring in the sample bottles within 24 hours.

A comparison of the replicate variation with the study period variation (Fig. 3) suggests that for all nutrient species, the replicate variation was minimal in relation to the month-to-month variation. The reasons for the monthly and month-to-month variations in the Souris River are dealt with in the section Nutrient Species and Ratios. Thus,

while there is a requirement for replicate sampling when characterizing a river cross section, it is not critical in determining the month-to-month or seasonal variations.

Nutrient Concentration of the Study Period and Other Dry Periods

Summary statistics of the study period and other dry years reveal that for both periods, even within a flow-period regime, the nutrient fluctuation was substantial (Table 2). This indicates the need for temporal sampling in characterizing a flow period. As observed in the section Nutrient Species and Ratios, the nutrient concentration in the Souris River is influenced by a combination of biological and chemical processes and physical occurrences, such as precipitation, runoff, and discharges from the J. Clark Salyer Reservoir. The low precipitation and runoff were particularly effective in lowering the nitrate- and nitrite-N concentrations. Historical data on file also show that generally higher nitrate- and nitrite-N concentrations in the Souris River occur with heavy precipitation and runoff. Overall, the range of fluctuations for nitrate- and nitrite-N during the study period and other dry years was greater than that of total-N and total-P. Maximum total-N fluctuations occurred during the low flow, open water period, while maximum total-P fluctuations occurred during low flow periods under ice cover.

A yearly breakdown of the various flow periods of the dry years and of the study period also reveals an identical pattern of maximum total-N and total-P concentrations occurring during the low flow period under ice cover and nitrate- and nitrite-N occurring during the low flow, open water period. The exceptions were the high total-N concentration during the 1977 low flow, open water period and the high total-P during the study period under ice cover. The cause of the high total-N is not known. A possible cause of the high total-P is suggested in the section Particulate Phosphorus.

Thus, a comparison of the study period data with the data from the other dry periods reveals that with minor exceptions (see the section Historical Data from Other Dry Periods), the total-N, nitrate- and nitrite-N, and total-P concentrations of the study period were comparable to those of the other dry periods. The agreement was most favourable for total-P and least for nitrate- and nitrite-N.

Nutrient Species and Ratios

Total Dissolved Organic Nitrogen

The substantial increases in total dissolved organic-N observed during the winter period probably resulted from a variety of sources, such as decomposition of flora and fauna, concentration effects from extreme winter freezing as reflected in the conductivity values (Table 4), and ground water. The cause of the July and August increases is believed to be the water released from the nutrient-rich J. Clark Salyer Reservoir. In 1980, because of the very low precipitation and runoff, it was necessary to lower the water level in the reservoir to maintain the 0.57 m^3/s discharge at the North Dakota-Manitoba border. This was accomplished by discharging water from near the bottom of the reservoir (T. Stewart, 1984, United States Fish and Wildlife Service, Bismark, N.D., pers. comm.).

Ammonia Nitrogen (Total)

Ammonia-N followed the same pattern that was observed for total dissolved organic-N (Table 3), and the high July and August concentration was probably also caused by the water released from the nutrient-rich J. Clark Salyer Reservoir. In January ammonia-N accounted for 52% of the total-N. Such increase in ammonia-N concentration during winter periods is documented elsewhere (Johannes, 1968; Keeney, 1973).

During the winter period, the temperature and pH were low (February, 0°C and pH 7.3). Thus virtually all of the ammonia-N was in the ionized NH^+_4 form. In July, however, when the temperature and pH were higher (18.5°C, pH 8.1), the un-ionized ammonia (NH_3) concentration was 0.04 mg/L, calculated after Emerson *et al.* (1975). This is twice the 0.02-mg/L limit suggested by the United States Environmental Studies Board (1973) for the protection of freshwater aquatic life. With such a large variation in concentration and ionization, it is obvious that a few samples per year are not sufficient for assessing the ammonia-N concentration in the Souris River.

Nitrate Nitrogen

Agricultural drainage is reported to have a total-N concentration ranging from 1 mg/L to more than 100 mg/L, mostly in the form of nitrate-N (McCarty *et al.*, 1970). In the Red River study, it was observed that as much as 60% of the total-N during a high spring runoff was nitrate-N. In the Souris River, nitrate-N was less than 1% of the total-N during the spring runoff. This apparently is a reflection of the low spring runoff and limited surface leaching during the dry years. The low summer concentrations probably resulted from rapid algal assimilation at this time. The maximum concentration observed during the early part of the winter (December and January), when the dissolved oxygen was above 7 mg/L (Table 4), is believed to be a result of limited biological uptake at this time. However, in February and March, when the dissolved oxygen was depleted (February, 0.5 mg/L; March, 0.0 mg/L),

nitrate-N was again at the detection level, suggesting denitrification in an anaerobic environment.

Nitrite Nitrogen

Except for the abnormally high concentrations in July and August 1980 (Table 3), the nitrite-N concentration was very low. The high July and August concentrations are attributed to the release from the J. Clark Salyer Reservoir previously referred to.

Particulate Nitrogen

Despite the very low spring runoff, particulate-N increased during the spring discharge and again in June. The spring increase apparently reflects the greater suspended matter observed at this time, and the June increase is attributed to high organic matter during the summer period.

Ortho-phosphorus

In contrast to the very low nitrate-N concentration observed in the Souris River, the ortho-P concentration remained high, constituting 65% of the study mean. It generally followed the total dissolved organic-N and ammonia-N pattern of having high winter and July and August concentrations. The February and March increases, at least in part, are attributed to the microbial mineralization of iron and manganese complexes taking place in the Souris River. Ortho-P release of iron and manganese complexes in an anaerobic condition is documented elsewhere (Wetzel, 1975). The concentrations of iron and manganese during February and March were abnormally high with a mean concentration of 1.1. and 3.3 mg/L, respectively. If the critical ortho-P concentration for algal bloom is accepted as 0.01 mg/L (Sawyer and McCarty, 1967), it was never a limiting factor in the Souris River.

Total Dissolved Organic Phosphorus

The overall total dissolved organic-P concentration was 10%, while the total dissolved organic-N was 62%. Although total dissolved organic-P of up to 31% was observed during the study period, which is similar to the 30% reported by Englebrecht and Morgan (1959), the overall concentration was low. Similar findings of less than 10% were observed in the Red River study as well.

Particulate Phosphorus

In contrast to other observations (Cahill, 1977; Ongley, 1978; Chacko *et al.*, 1981), the maximum particulate-P concentrations occurred in the winter period under ice cover and not with the spring discharge. The abnormally high concentration in February apparently coincided with an increased discharge from the J. Clark Salyer Reservoir. A frozen control gate of the reservoir was forced open, resulting in an increased discharge of water and suspended sediment (T. Stewart, 1984, United States Fish and Wildlife Service, Bismark, N.D., pers. comm.).

Overall, the particulate-P ratio was low. It was only 25% of the study period total-P. If the February value is removed, it was only 18% of the study period total-P, which was substantially lower than the 54% observed in the Red River study and an even greater percentage lower than that reported by Cahill (1977). The major cause of this overall low particulate-P content is believed to be the low spring runoff previously referred to.

The P:N Ratios

Phosphorus is suggested as a limiting growth factor for algae when the atomic ratio of inorganic-N (ammonia-N and nitrate- and nitrite-N) to ortho-P is greater than 10 (Chiaudani and Vighi, 1974). In the Souris River this ratio was generally lower than 10, and on two occasions lower than 1 (Table 5). The reason for this very low ratio of inorganic-N to ortho-P during the 1979/80 study period is the low nitrate-N, apparently resulting from the limited surface runoff. With the exception of the August 1980 ratio, which is attributed to the reservoir release, the maximum ratios were observed during the early part of the winter period. As suggested earlier, decomposition of organic matter by heterotrophic bacteria, when phytoplankton uptake was low, probably resulted in this higher inorganic-N concentration. The reason for the low ratios of inorganic-N during the summer period is believed to be the rapid biological uptake during this period. Similar observations of high winter and low summer ratios of inorganic-N to ortho-P are reported by Allan and Roy (1980) in the Qu'Appelle River. The inorganic-N to ortho-P ratios in Table 5 suggest that, overall, the Souris River is an inorganic-N–limited river rather than an ortho-P–limited one. It stands to reason, therefore, that the anticipated increase in inorganic-N concentration resulting from the GDUP could result in increased biological productivity in the Souris River. The decomposition of this biomass would further reduce the dissolved oxygen levels during the winter period and thus prolong the anaerobic conditions.

If the 1:16 atomic P:N ratio of plant cells (algae and bacteria), as reported by McCarty *et al.* (1970), is accepted as a basis of comparison, most of the particulate-P and particulate-N ratios of the summer period suggest plant origin. The substantially different ratios of the winter period, mostly resulting from the increased particulate-P concentration (see the section Particulate Phosphorus), suggest non-plant sources.

Table 5. Concentrations and Atomic Ratios of Inorganic-N to Ortho-P and Particulate-P to Particulate-N

Sampling date	Inorg-N (mg/L)	Ortho-P (mg/L)	Atomic N:P	Part-P (mg/L)	Part-N (mg/L)	Atomic P:N
79-08-02	0.07	0.30	1:2	0.04	0.28	1:17
79-08-21	0.05	0.20	1:2	0.02	0.13	1:16
79-09-27	0.12	0.16	2:1	0.07	0.26	1:9
79-10-29	0.04	0.03	3:1	0.09	0.40	1:11
79-11-28	0.14	0.06	6:1	0.05	0.26	1:13
79-12-19	0.45	0.08	14:1	0.10	0.65	1:16
80-01-29	1.47	0.30	12:1	0.19	0.26	1:3
80-02-26	0.73	0.74	2:1	0.57	0.20	1:1
80-03-25	1.79	1.66	3:1	0.28	0.22	1:2
80-04-29	0.03	0.03	2:1	0.13	0.73	1:14
80-05-22	0.06	0.11	1:1	0.02	0.10	1:12
80-06-17	0.04	0.02	5:1	0.08	0.75	1:23
80-07-30	0.97	0.43	5:1	0.04	0.43	1:27
80-08-13	1.50	0.29	13:1	0.04	0.27	1:17

CONCLUSIONS

Replicate sampling was more important for the nitrogen species than for the phosphorus species. For both species, however, the cross-sectional variation was minimal in comparison to the month-to-month variations, and therefore multiple sampling was not critical in determining the seasonal variations.

Even within a flow-period regime, the nutrient concentration varied substantially, indicating the need for temporal sampling during that period to characterize a flow period. The maximum variations within a flow period were observed for nitrate- and nitrite-N, followed by total-N and total-P. The 1979/80 concentrations of these nutrients were similar to other dry periods.

The nitrogen and phosphorus species in the Souris River at Coulter appear to have been influenced by the releases from the J. Clark Salyer Reservoir. The predominant nitrogen species were total dissolved organic-N (62%), ammonia-N (20%), and particulate-N (15%). During the summer period, the un-ionized ammonia-N concentration was well above the 0.02-mg/L limit suggested for the protection of freshwater aquatic life. The predominant phosphorus species were ortho-P (65%), particulate-P (25%), and total dissolved organic-P (10%). Ortho-P always was well above the 0.01-mg/L critical level suggested for algal bloom. Overall, the Souris River is an inorganic-N-limited stream rather than an ortho-P-limited one.

RECOMMENDATIONS

1. Multiple samples should be collected when determining the nitrogen and phosphorus species concentration at a cross section of the Souris River. (It is more important for the nitrogen species than for the phosphorus species.)

2. Further investigation should be carried out in order to determine whether the observed replicate variation was caused by the heterogeneity of the river cross section or by the different rate of nutrient species transformation continuing in the sample bottles.

3. The routine sampling for nutrient determination should be carried out several times during each flow period. The exact frequency has to be determined by examining the daily nutrient data.

4. During the summer period when pH is higher than 8.5, additional sampling for ammonia-N should be carried out.

5. If the inorganic-N concentration in the Souris River increases as a result of the Garrison Diversion Unit Project, the discharge should be increased during the winter period in order to minimize the impact of biomass decomposition.

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APPENDIX A

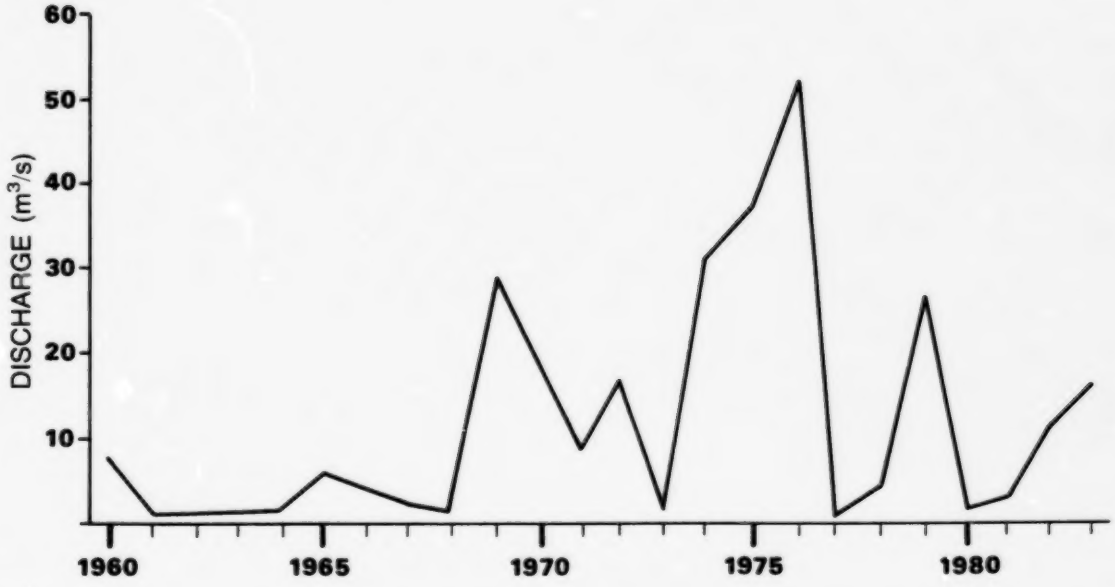

Figure A-1. Annual Mean Discharge—Souris River at Coulter (1960-1983).